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Effects of replacing oak-woods by eucalyptus on edaphic Collembola communities: does the size and type of plantation matter?

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RESUMO

Neste trabalho os autores analisam o efeito da substituição de bosques de *Quercus pyrenaica* Willd. por pequenas plantações não geridas de *Eucalyptus globulus* Labill. ao nível das comunidades de Colêmbolos edáficos, num sistema agro-florestal no Norte de Portugal. A instalação da plantação originou alterações ao nível da configuração do habitat (quer ao nível da estrutura da vegetação, quer ao nível de diversos parâmetros físico-químicos do solo) quando comparada com a existente no povoamento florestal autóctone. Estas novas condições eco-climáticas deram origem a uma composição faunística diferente, tendo ocorrido a redução de espécies raras ou de distribuição restricta (especialmente dos grupos Isotomidae e Onychiuridae) e a um aumento das espécies expansivas ou sem grandes exigências em termos de humidade e/ou matéria orgânica (principalmente dos grupos Entomobryidae e Neanuridae). No entanto, as alterações ao nível dos padrões de biodiversidade não foram tão marcantes. Apesar do menor número de taxa identificados e da menor diversidade e riqueza específicas observadas no povoamento de eucalipto, estes indicadores foram fortemente influenciados pela elevada abundância das espécies dominantes, o que implica uma análise atenta destes valores. A análise global dos resultados parece indicar que, ao nível das comunidades de colêmbolos, a instalação de pequenas parcelas florestais, onde as actividades de maneio florestal sejam reduzidas, pode originar uma alteração na estrutura da comunidade, mas não necessariamente uma forte quebra na biodiversidade, pelo menos na forma como ela é medida. Mais ainda, o grau de alteração do habitat causado pela instalação do povoamento, especialmente ao nível dos principais factores edáficos que regulam a distribuição das espécies (humidade do solo, teor e tipo de matéria orgânica), irá influenciar a magnitude do efeito ao nível destes artrópodes.

ABSTRACT

In this study the authors analyse the effects of replacing coppices of *Quercus pyrenaica* Willd. by small, non managed, *Eucalyptus globulus* Labill. plantations on soil Collembola communities in a typical agro-forest system in Northern Portugal. The installation of the exotic tree species induced significant changes in the microhabitat configuration for collembola (in terms of vegetation structure and soil physical and chemical parameters) when compared to the conditions present in the autochthonous stand. These new eco-climatic conditions originated a different species composition mainly characterised by the reduction of rare and restricted distribution species (mostly Isotomidae and Onychiuridae), and the increase of expansive or not so demanding species in terms of soil moisture and/or organic matter content (mainly Entomobryidae and Neanuridae). However the changes in biodiversity patterns were not so strong; despite the lower number of taxa and the lower species diversity and species richness values found on the eucalyptus site, these indicators were strongly influenced by the high abundance of the dominant species, needing a non straightforward analysis. Therefore, the data obtained here indicates that the effects on the collembola community, when installing small areas of eucalyptus where management practices are almost absent during tree growth, may imply a change in species composition, but not necessarily a strong biodiversity loss (at least as we measure it). Moreover, the degree of change induced in the habitat by the installation of the plantation, especially on those soil factors ruling species distribution (soil moisture and organic matter content and quality), will dictate the magnitude of effects.

INTRODUCTION

After forest fires, the plantation of extensive areas with the exotic tree species *Eucalyptus globulus* Labill. can be considered one of the most important subjects of debate regarding the ecological stability of forest ecosystems in Portugal. Despite the strict policy ruling the plantations of this exotic species, and the efforts made by landowners to improve the management techniques of existing eucalyptus plantations, the area occupied by this species is still increasing, although at a slower rate than the observed in the past.

Occupying c.a. 21% of the forested area (DGF, 2001), the actual distribution of this species comprises mainly the north western half of the country, the area on the western border between Alentejo and Algarve provinces (in the south), and with only one incursion into the mainland along the Tejo river (in the centre). This distribution has been made at costs not only of productive agricultural land, but also by replacing native forests with this exotic species. Being an evergreen fast-growing species, eucalyptus may have a strong impact not only on soil, but also on fauna and landscape structure. The magnitude of impacts is generally associated with the dimensions of the planted area (higher global effects on large and continuous stands), the type of stand (pure or mixed plantations) and the forestry techniques adopted during the installation and subsequent management of the plantation.

Collembola are sensitive to changes in microclimate conditions, such as those caused by forest activities. They are also sensitive to numerous changes in soil parameters, namely soil moisture, soil chemistry and plant composition, thus being important bioindicators of human induced changes in soil system (Lauga-Reyrel & Deconchat, 1999). The effects of eucalyptus plantation in Portugal on collembola communities have been evaluated since the last two decades, mainly by comparing the fauna from stands of this exotic species with the collembola fauna existing on contiguous forests of autochthonous tree species (Barrocas *et al.*, 1998; Ferreira *et al.*, 1994; Figueiredo *et al.*, 1985; Gama *et al.*, 1989, 1991, 1994, 1994a; 1995; Pinto *et al.*, 1997; Sousa & Gama, 1994; Sousa *et al.*, 1997; Vasconcelos *et al.*, 1994). Special attention has been devoted to those autochthonous species most affected by an increase of eucalyptus plantation (e.g., *Quercus suber* L., *Q. ilex* ssp. *ballota* (Desf.) Samp. and *Pinus pinaster* Aiton) and to those areas where this phenomenon was more intense (managed plantation areas in central Portugal). The results found indicate that shifting towards eucalyptus led to an impoverishment of collembola communities and that the magnitude of the effects was mainly induced by the habitat configuration found on the exotic stand, this being a consequence of the management techniques (intensity and frequency) used to run the plantations.

This study, however, is focused on other type of situation. Again, a collembola community from an autochthonous stand (*Q. pyrenaica* Wild) is compared with the collembola community existing under eucalyptus. But in this case, this exotic does not occupy an extensive area nor is managed as a traditional plantation. The type of landscape is a typical agro-forest system in Northern Portugal, where forested areas build a mosaic with small pastures or small agricultural parcels. The major goal of this study is to evaluate whether the introduction of the eucalyptus per se could induce some disruption in collembola communities, independent of the size of the planted areas and on the absence of management during rotation cycles. Moreover, the change of soil parameters due to the reforestation is also evaluated and a detailed analysis of collembola species distribution influenced by these parameters is done, linking both aspects.

MATERIALS AND METHODS

Study area

The selected black oak (*Q. pyrenaica*) forest and the eucalyptus stand are located in the small village of Gontim, nearby the town of Fafe (district of Braga, province of Minho) in the north of Portugal. Located at 350 m of altitude, the area is a typical agro-forest ecosystem of this region known as "Terras Altas". The landscape is characterised by a mosaic of forested areas (mainly with oak, chestnut and pine) with small pastures and arable parcels. The forested areas are not heavily managed. From time to time clear cuts occur, mainly on pine, and oaks are pruned to produce charcoal and wood. Eucalyptus occupies only small areas, and in most cases trees were planted by private landowners in less productive pasture or agricultural spots, or in small parcels of forested areas, replacing autochthonous tree species. The great majority of these small plantations are not managed and the soil is only disturbed when trees are planted and cut (if occurring). The climate of the area is very humid, with 1700 mm total rainfall/year, mesothermic (mean annual temperature of 15 °C), with a moderate water deficiency during summer. The soil is a dystric cambissoil, dominated by granite, thus having an acidic pH (4.5 - 5.6).

The dominant vegetation of the black oak stand was composed by mature oaks (more than 30-40 years old) and by young, shrub like, oak trees (resulting from natural regeneration), that at *Alfa* experimental unit (see sampling design below) composed a dense shrub layer. The herbaceous layer was abundant and composed mainly by *Briza maxima* L., *Avena sterilis* L., *Hordeum murinum* L., *Asphodelus lusitanicus* P. Cout., *Scilla hispanica* Miller, *Armaria montana* L., *Erica arborea* L. and *Lavandula stoechas* L.. The shrub layer was in some cases dense and composed mainly by *Chamaespartium tridentatum* (L.) Gibbs and *Retama monosperma* L.. Soil was covered by a thick and homogeneous layer of oak leaves in different stages of decomposition.

The vegetation of the eucalyptus stand was less diverse. Trees were mature (with 12 to 15 years old) and the stand was in the second rotation. No clear signs of management were visible. Shrub layer was almost absent (with the exception of *Miu* experimental unit where small oak shrubs were found) and the herbaceous layer was composed mainly by ferns in *Alfa* and *Beta* experimental units, and by *B. maxima* and *E. arborea* in the other two experimental units. Leaf layer was not uniform along the area, and when existing was much thinner and composed by eucalyptus and oak leaves.

Sampling design, sampling and soil characterization

At each stand, four experimental units (squares with eight per eight meters designated *Alfa*, *Beta*, *Gamma* and *Miu*) were randomly selected and each one was divided into 16 small squares (two per two meters). At each experimental unit four squares, out of 16, were selected and assigned as sampling points, following a typical nested design.

At each sampling point, and after the careful removal of the litter layer (leaves not yet decomposed) two 250cm^3 samples at different depths were taken: one at the humus layer, and another at the superficial mineral soil. At each stand, a total of 32 samples were taken. After sampling, the thickness of the humus layer, and soil temperature were measured.

In the laboratory mesofauna was extracted by placing samples in Berlese-Tullgren funnels for seven days. Afterwards the biological material was sorted under a stereo microscope and collembola identified until species level. Samples from both horizons were used to make a site characterization by measuring several abiotic parameters: water content (dried overnight at 105°C), soil pH (measured in 1M KCl 1:6 v:v), organic matter content (after combustion in a muffle at 500°C for 6 hours) and nitrogen and carbon contents (Kjeldhal's and Anne's methods respectively).

Statistical analysis

Differences on soil abiotic parameters, collembola abundance and number of taxa among experimental units and between sites were determined using a Nested ANOVA (Zar, 1996). Data was checked for normality and homogeneity of variances using the Kolmogorov-Smirnov and Bartlett tests respectively. In those cases where these assumptions were violated, data was transformed accordingly. Parametric analysis was done using the STATISTICA software package.

To detect a separation between sites in relation to soil abiotic parameters (= environmental variables), a Principal Component Analysis (PCA) was done based on a correlation matrix and using a "sampling points *vs.* parameters" matrix as original data. Collembola communities were also analysed by multivariate techniques. Firstly a Correspondence Analysis (CA) was done just to detect any change in community composition using a "experimental units vs. taxa" matrix as raw data. Afterwards, a Canonical Correspondence Analysis (CCA) was done in order to detect and visualise the relation between taxa and environmental variables and to evaluate which factors determine species distribution (Ter Braak, 1986). On this analysis two data matrices were used ("sampling points vs. taxa" and "sampling points vs. parameters"), and the relation between species and the whole set of environmental variables was tested using a Monte Carlo permutation test. Both on CA and CCA methods, species abundances were log transformed prior to analysis. Multivariate analyses were done in CANOCO 4.0 software.

Moreover several diversity indices were calculated. Species diversity and evenness (Shannon), species richness (Margalef) and dominance (Berger-Parker) were evaluated for both horizons, either considering all samples together or individual experimental units. To detect the degree of change in species distribution inside each stand, the between-sample diversity (β-diversity) were evaluated according to Magurran (1991). In these calculations, and in the multivariate analysis using collembola, those taxa where only one individual was identified (considering the 64 samples analysed) were discarded from analysis.

RESULTS

Soil chemical and physical characterization

ANOVA results showed only significant differences between both sites on some of the parameters measured (Fig.1). The thickness of the humus layer, its water and organic matter contents were higher on the oak site than at the eucalyptus stand. The same occurred with the water content of the superficial soil layer. Another parameter where a significant difference was found was soil temperature. In this case, however, the eucalyptus site presented higher values than the oak stand, which may indicate a more exposed habitat. On the other parameters measured, no significant differences between areas were found. However in the majority of them, a significant difference between experimental units inside each stand was found. This is particularly true for nutrient and soil organic matter values in eucalyptus stand and for water content values at the oak site (Fig. 1). These differences indicate the spatial variability present at each site, that associated with the vegetation structure, will influence the local distribution of species.

The biplot derived from the Principal Component Analysis (Fig. 2) shows a clear separation of oak and eucalyptus sampling points along the main axis (which explains 46.3% of total variability). Among the parameters contributing most for this separation are those mentioned above. In fact the oak site seems to be characterised by a good quality of both horizons, although parameters measured on the soil layer contribute more for the separation of points along axis one. This quality is generally related not only to higher nutrient and organic matter contents, but also to higher water content. The eucalyptus site, despite the absence of significant differences in most parameters, is characterised by a less rich soil. In this case soil temperature is the factor pushing eucalyptus samples towards the positive side of the axis.

The second axis explained 16.8% of total variability, and separates sampling points mainly according to their C:N ratios of both horizons. The broader distribution of eucalyptus points along this axis is indicative of the great variability inter and intra sampling units existing on these parameters, as clearly shown in Fig. 1.

Collembola composition – Abundance, Taxa and Biodiversity indicators

A total of 8679 individuals were collected on both sites, separated into 45 different taxa (Table I). ANOVA results showed no significant differences between sites neither in abundance or number of taxa in any of the comparisons made (each layer separately or all strata together). Regarding this last

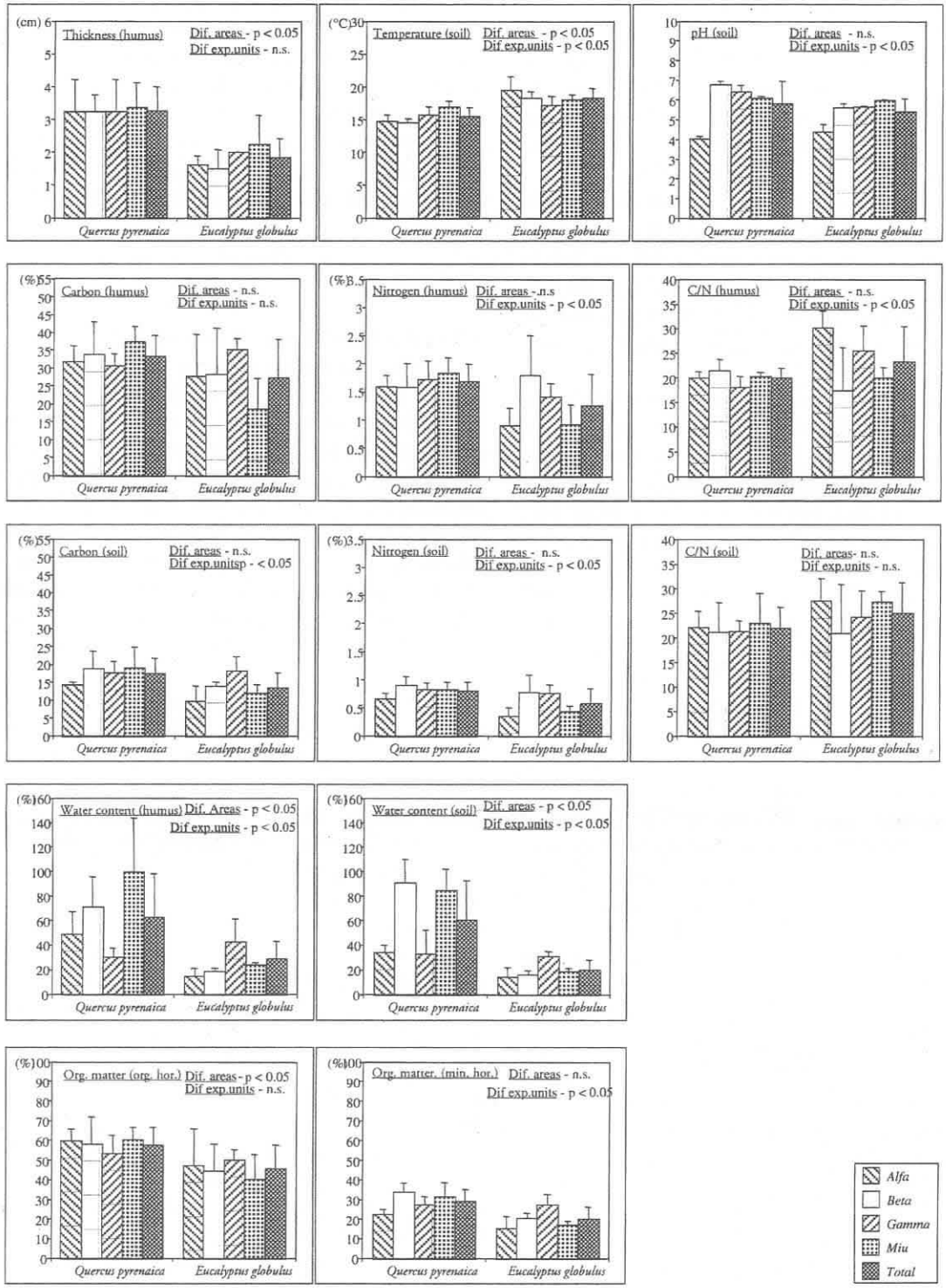
(cm) Thickness (humus) Dif. areas - p < 0.05 Dif exp.units - n.s.
(°C) Temperature (soil) Dif. areas - p < 0.05 Dif exp.units - p < 0.05
pH (soil) Dif. areas - n.s. Dif exp.units - p < 0.05
(%) Carbon (humus) Dif. areas - n.s. Dif exp.units - n.s.
(%) Nitrogen (humus) Dif. areas -.n.s Dif exp.units - p < 0.05
C/N (humus) Dif. areas - n.s. Dif exp.units - p < 0.05
(%) Carbon (soil) Dif. areas - n.s. Dif exp.unitsp - < 0.05
(%) Nitrogen (soil) Dif. areas - n.s. Dif exp.units - p < 0.05
C/N (soil) Dif. areas- n.s. Dif exp.units - n.s.
(%) Water content (humus) Dif. Areas - p < 0.05 Dif exp.units - p < 0.05
(%) Water content (soil) Dif. areas - p < 0.05 Dif exp.units - p < 0.05
(%) Org. matter (org. hor.) Dif. areas - p < 0.05 Dif exp.units - n.s.
(%) Org. matter. (min. hor.) Dif. areas - n.s. Dif exp.units - p < 0.05
Quercus pyrenaica
Eucalyptus globulus
Alfa
Beta
Gamma
Miu
Total

Figure 1 – Average values (+ SD) from the physical-chemical parameters at the different experimental units of *Q. pyrenaica* and *E. globulus* sites. The significance values from the Nested ANOVA are also indicated.

variable, this result was expected due to the similar number of species found on both sites, despite the slightly higher number of species identified on the oak stand (Table II). In relation to abundance, the great variability observed between samples and among different experimental units (Table II) was the cause for the absence of significant differences.

At the oak site collembola community was dominated by *Folsomia quadrioculata*, representing approximately 40% of the identified animals (1734 individuals). This species, occurring exclusively in this stand, was replaced by another Isotomidae species, *Tetracanthella proxima*, in the eucalyptus site. This species dominates the community in the exotic stand with 3859 individuals identified (more than 80%). Collembola communities on both sites are quantitatively dominated by a few number of species; in oak stand 30% of the species represent more than 90% of the individuals, while in eucalyptus

Table 1 - Total abundance and number of taxa collected on both stands

		Quercus pyrenaica			*Eucalyptus globulus*		
Code	*Taxa*	**Humus**	**Soil**	**Total**	**Humus**	**Soil**	**Total**
Cen	*Ceratophysella engadinensis* Gisin, 1949	5	4	9		35	35
Cgi	*Ceratophysella gibbosa* (Bagnall, 1940)					3	3
Cte	*Ceratophysella tergilobata* Cassagnau, 1954	1		1	5	15	20
Xgr	*Xenylla grisea* Axelson, 1900	12		12			
Xsc	*Xenylla schillei* Börner, 1903	6		6			
Xar	*Xenyllodes armatus* Axelson, 1903	190	34	224		1	1
Asp	*Anurida* sp.		1	1	1		1
Bau	*Bilobella aurantiaca* Caroli, 1912	3	3	6			
Dsy	*Deutonura deficiens sylvatica* Deharveng, 1982	1		1	2		2
Dpo	*Deutonura portucalensis* (Gama, 1964)	2		2	1	20	21
Misp	*Micranurida* sp.	1		1		2	2
Pbo	*Pseudachorudina bougisi* Delamare, 1951	2		2	34	65	99
Pas	*Pseudachorutella asigillata* (Börner, 1901)	1		1	1	1	2
Ppa	*Pseudachorutes palmiensis* Börner, 1903		3	3			
Psu	*Pseudachorutes subcrassus* Tullberg, 1871				4	2	6
Rsp	*Rusekella* sp.				6	5	11
Sla	*Superodontella lamellifer* (Axelson, 1903)				2	1	3
Sgi	*Superodontella gisini* (Gama, 1961)		4	4			
Msp	*Mesaphorura* sp.	158	205	363	13	49	62
Osp	*Onychiurus* sp.	8	16	24		2	2
Par	*Protaphorura armata* (Tullberg, 1869)	30	68	98			
Pgar	*Protaphorura* gr. *armata*	5	9	14			
Pgi	*Protaphorura gisini* (Haybach, 1960)		3	3	10	31	41
Cde	*Cryptopygus debilis* (Cassagnau, 1959)	44	24	68			
Csc	*Cryptopygus scapelliferus* (Gisin, 1955)	57	55	112		1	1
Cth	*Cryptopygus thermophilus* (Axelson, 1900)	59	10	69	2	7	9
Fde	*Folsomia decopsis* Steiner, 1958	189	137	326	33	40	73
Fqu	*Folsomia quadrioculata* (Tullberg, 1871)	1202	532	1734			
Fsp	*Folsomia* sp.				2		2
Imi	*Isotomiella minor* (Schäffer, 1896)	303	127	430	16	9	25
Ifu	*Isotomurus fucicolus* (Reuter, 1891)		2	2			
Ijuv	*Isotomurus* juv.	2	1	3			
Thy	*Tetracanthella hygropetrica* Cassagnau, 1954	20	18	38			
Tpr	*Tetracanthella proxima* Steiner, 1955	2		2	931	2928	3859
Emu	*Entomobrya multifasciata* (Tullberg, 1871)	101	3	104	6		6
Esp	*Entomobrya* sp.	74	5	79	132	3	135
Ejuv	*Entomobrya* juv.		2	2	34	8	42
Hma	*Heteromurus major* Moniez, 1889	64	3	67	23	6	29
Lsp	*Lepidocyrtus* sp.	37		37	10	2	12
Pin	*Pseudosinella infrequens* Gisin & Gama, 1969	16	5	21	7	5	12
Ppi	*Pseudosinella picta* Börner, 1903	9	1	10			
Psp	*Pseudosinella* sp.	3	1	4		1	1
Pssp	*Pseudosinella* sp.2	10	1	11	2	2	4
Enjuv	*Entomobryidae* juv.	154	64	218	14	30	44
Ajuv	*Arrhopalites* juv.		2	2			
	Abundance	**2771**	**1343**	**4114**	**1291**	**3274**	**4565**
	Number of *Taxa*	**33**	**30**	**40**	**24**	**27**	**31**

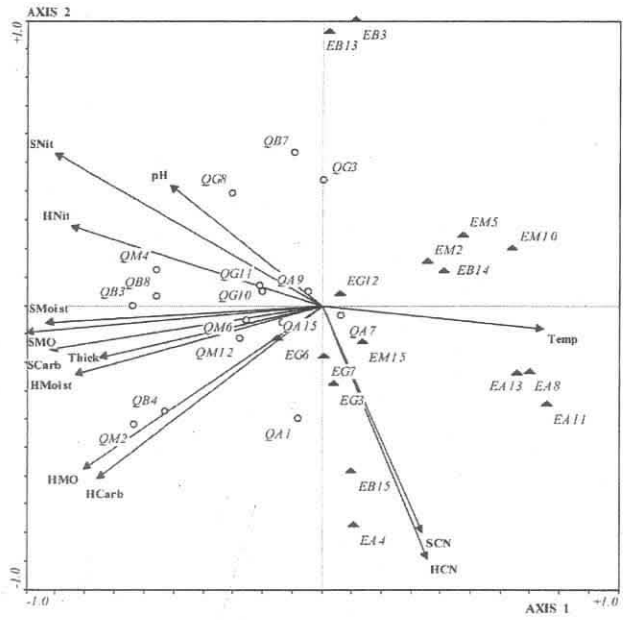

Figure 2 – Biplot of the Principal Component Analysis based on "soil parameters vs sampling points" matrix. Open circles (*Q. pyrenaica* sampling points); black triangles (*E. globulus* sampling points). Representation of the sampling points (example): QA1 (oak site, experimental unit *Alfa*, sampling point 1); EA13 (eucalyptus site, experimental unit *Alfa*, sampling point 13). Soil parameters: **Thick** (thickness of the humus layer); **Temp** (temperature of the upper soil layer); **pH** (pH of the upper soil layer); **HMoist** or **SMoist** (water content in the humus or upper soil layer); **HCarb** or **SCarb** (carbon content of the humus or upper soil layer); **HNit** or **SNit** (nitrogen content of the humus or upper soil layer); **HMO** or **SMO** (organic matter content of the humus or upper soil layer); **HCN** or **SCN** (C:N ratio content of the humus or upper soil layer).

site, this percentage of total abundance is represented only by 10% of the species identified (analysis of Table I).

The taxonomic profile in terms of abundance is also highly influenced by these two species. Isotomidae dominate the spectrum on both stands, with percentage values being slightly higher in eucalyptus (Table III). In this stand, this increase is parallel to a decrease of the Hypogratruridae and Onychiuridae, and a gain in the percentage of Neanuridae. Odontellidae and Symphypleona have a poor representation due to the reduced number of individuals identified. In relation to the number of taxa, the obtained spectrum is different. At the oak site, the Isotomidae and the Entomobryidae are equally represented, followed by the Neanuridae, the Onychiuridae and the Hypogastruridae (Table III). When comparing the results on both sites, at the eucalyptus we could observe a decrease in the number of species of the Isotomidae and Onychiuridae, and an increase in the representativity of the Neanuridae and Entomobryidae.

Analysing biodiversity indicators, the oak site presented a higher species diversity and species richness than the eucalyptus site, either considering the results per experimental unit or globally (Table II). Observing the differences among CV values between sites, it is possible to notice that at the oak site, individuals and taxa (also in terms of diversity) are more evenly distributed than at the eucalyptus stand. In this case, the higher CV values reflect a more clumped distribution, probably associated with the habitat diversity found in this stand. This higher degree of change in species distribution is also given by the slightly higher β-diversity values obtained for the exotic stand (Table II).

Table II - Average (SD) and coefficient of variation values for abundance, number of taxa and diversity indicators obtained per experimental unit and globaly at each stand.

	Quercus pyrenaica			*Eucalyptus globulus*		
Per Exp. Unit	**Humus**	**Soil**	**All stata**	**Humus**	**Soil**	**All stata**
Abundance	692.8 (465.4)	335.8 (169.8)	514.3 (376.3)	322.8 (154.9)	818.5 (701.8)	570.6 (540.0)
CV	67.2	50.6	73,2	48.0	85.7	94,6
Taxa	18.5 (1.7)	16.0 (2.2)	17.3 (2.3)	12.5 (5.9)	12.0 (1.4)	12.3 (4.0)
CV	9.4	13.5	13,1	47.3	11.8	32,6
Diversity (H')	2.59 (0.12)	2.60 (0.36)	2.59 (0.25)	1.55 (1.08)	1.02 (0.73)	1.29 (0.90)
CV	4.7	13.9	9,6	69.6	71.6	69,9
Evenness (E)	0.62 (0.03)	0.65 (0.06)	0.63 (0.05)	0.41 (0.23)	0.28 (0.19)	0.34 (0.21)
CV	4.3	9.9	7,7	56.9	68.4	60,4
Richness (D)	2.78 (0.33)	2.66 (0.62)	2.72 (0.46)	2.04 (1.03)	1.71 (0.27)	1.87 (0.72)
CV	11.8	23.2	17,0	50.6	15.6	38,4
Dominance (BP)	0.48 (0.09)	0.41 (0.12)	0.44 (0.11)	0.69 (0.25)	0.84 (0.14)	0.77 (0.20)
CV	19.3	30.1	23,9	36.7	16.4	26,7
Global	**Humus**	**Soil**	**All stata**	**Humus**	**Soil**	**All stata**
Abundance	2771	1343	4114	1291	3274	4565
Taxa	33	30	40	24	27	31
Diversity (H')	3,12	3,00	3,16	1,78	0,88	1,22
Evenness (E)	0,62	0,61	0,59	0,39	0,18	0,25
Richness (D)	4,04	4,03	4,69	3,21	3,21	3,56
Dominance (BP)	0.43	0.40	0.42	0.72	0.89	0.85
β-diversity	0,78	0,88	1,31	0,92	1,25	1,52

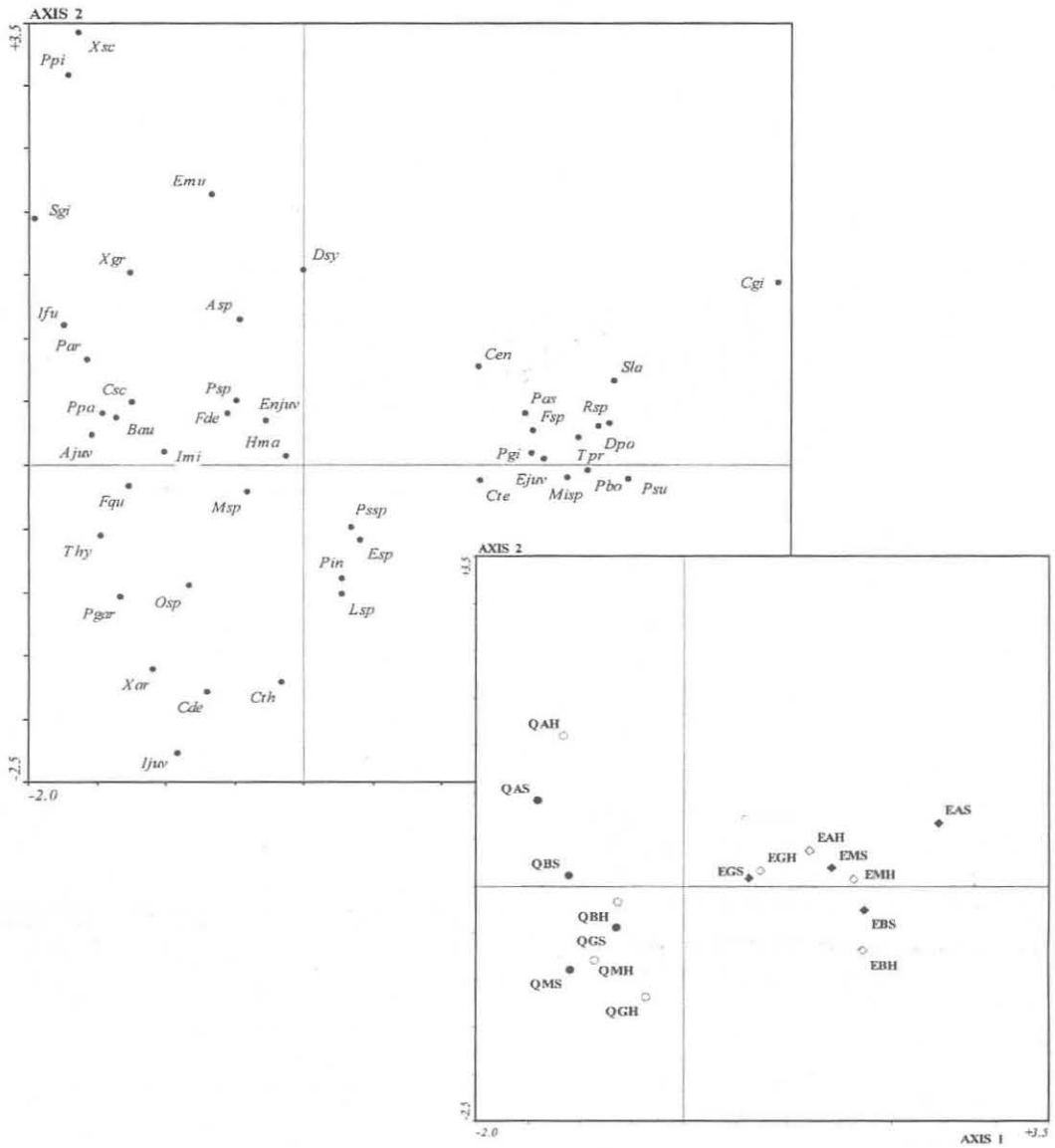

Figure 3 – Biplot of the Correspondence Analysis based on the "species vs experimental units" matrix. Open circles (*Q. pyrenaica* experimental units – humus layer); black circles (*Q. pyrenaica* experimental units – soil layer); open diamonds (*E. globulus* experimental units – humus layer); black diamonds (*E. globulus* experimental units – soil layer). Species codes as in Table I.

Collembola composition – Community structure

The biplot resulting from the correspondence analysis (Fig. 3) shows a clear separation of both sites along axis one (which represents 28.2% of total variability). Plotted on the negative side are those species found exclusively or clearly dominating on the oak site. These are represented mainly by Isotomidae species like *F. quadrioculata* (Fqu), *Folsomia decopsis* (Fde), *Cryptopygus debilis* (Cde), *Cryptopygus thermophilus* (Cth), *Cryptopygus scapelliferus* (Csc), *Tetracanthella hygropetrica* (Thy) and *Isotomiella minor* (Imi). However, some Onychiuridae, Hypogastruridae and Entomobryidae taxa are also representative of this group: *Protaphorura armata* (Par), *Mesaphorura* sp. (Msp), *Xenyllodes armatus* (Xar) and *Entomobrya multifasciata* (Emu). On the far positive side of the main axis we can found those species that characterise the exotic stand: *T. proxima* (Tpr), *Pseudachorudina bougisi* (Pbo), *Deutonura portucalensis* (Dpo), *Protaphorura gisini* (Pgi), *Ceratophysella engadinensis* (Cen), *Ceratophysella tergilobata* (Cte) and *Entomobrya* juv. (Ejuv). Those species occurring exclusively on eucalyptus (*Ceratophysella gibbosa, Pseudachorutes subcrassus* and *Rusekella* sp.) are also plotted, but they have a feeble abundance. Having a more central position we can find those species that despite dominating in one of the sites, are reasonably represented on the other site. This is the case for the Entomobryidae species *Entomobrya* sp. (Esp). *Heteromurus major* (Hma), *Lepidocyrtus* sp. (Lsp), *Pseudosinella infrequens* (Pin) and, in a lower extent, Entomobryidae juv. (Enjuv).

Axis two (representing only 12% of total variability) separates the experimental units from each site and not the two soil layers. This is more evident on the eucalyptus stand, meaning that the similarity between species composition is higher vertically than horizontally. This feature enhances the higher spatial heterogeneity observed in this site caused by the differences in habitat configuration.

Collembola composition – Relation between species and soil parameters

The relationship between species and soil factors laying behind the difference in community structure between sites is quite visible in the outcome of the Canonical

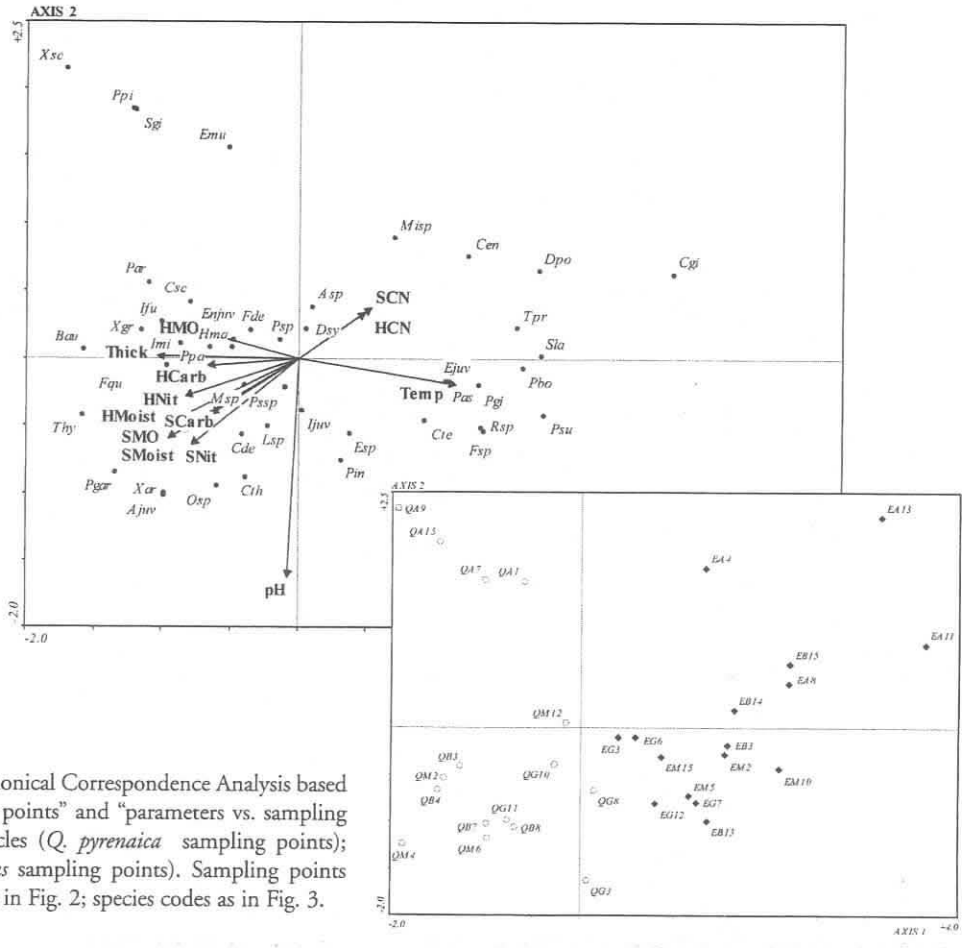

Figure 4 – Biplot of the Canonical Correspondence Analysis based on the "species vs sampling points" and "parameters vs. sampling points" matrices. Open circles (*Q. pyrenaica* sampling points); black diamonds (*E. globulus* sampling points). Sampling points and soil parameters codes as in Fig. 2; species codes as in Fig. 3.

Correspondence Analysis (Fig. 4). The distribution of species and sites in the biplot is quite similar to the analysis presented above. Moreover, the correlation between species and soil parameters is high and significant (see CCA summary at Table IV).

On axis one (representing 33.2% of total variability), those parameters influencing most the distribution of species (having the higher correlation coefficients) are the thickness of the humus layer, soil temperature and the water and organic matter contents of both layers. These variables

Table III - Taxonomic spectrum (%) for abundance and number of taxa obtained on each stand.

	Quercus pyrenaica			*Eucalyptus globulus*		
Abundance	Humus	Soil	All Strata	Humus	Soil	All Strata
Hypogastruridae	7,7	2,8	6,1	0,4	1,6	1,3
Neanuridae	0,4	0,5	0,4	3,8	2,9	3,2
Odontellidae	0,0	0,3	0,1	0,2	0,0	0,1
Onychiuridae	7,3	22,4	12,2	1,8	2,5	2,3
Isotomidae	67,8	67,5	67,7	76,2	91,2	86,9
Entomobryidae	16,9	6,3	13,4	17,7	1,7	6,2
Symphypleona	0,0	0,1	0,0	0,0	0,0	0,0
Taxa	Humus	Soil	All Strata	Humus	Soil	All Strata
Hypogastruridae	15,2	6,7	12,5	4,2	14,8	12,9
Neanuridae	18,2	10,0	20,0	29,2	22,2	25,8
Odontellidae	0,0	3,3	2,5	4,2	3,7	3,2
Onychiuridae	12,1	16,7	12,5	8,3	11,1	9,7
Isotomidae	27,3	30,0	25,0	20,8	18,5	19,4
Entomobryidae	27,3	30,0	25,0	33,3	29,6	29,0
Symphypleona	0,0	3,3	2,5	0,0	0,0	0,0

Table IV - Summary of the Canonical Correspondence Analysis and Correlation coefficients obtained between environmental variables and ordination axis.

CCA Summary	**Axis 1**	**Axis 2**
Eigenvalue	0,487	0,211
Species-Environmental Correlation	0,954	0,931
Variance explained (%)	33,2	14,4
Monte-Carlo test		
F	4,382	
p	<0.05	
Correlation coefficients	**Axis 1**	**Axis 2**
Humus layer parameters		
Thickness	-0,72	0,01
Water content	-0,67	-0,28
Carbon	-0,47	-0,03
Nitrogen	-0,58	-0,16
C:N ratio	0,35	0,19
Organic matter	-0,61	0,13
Soil layer parameters		
Temperature	0,82	-0,11
pH	-0,05	-0,92
Water content	-0,67	-0,34
Carbon	-0,45	-0,23
Nitrogen	-0,55	-0,37
C:N ratio	0,37	0,22
Organic matter	-0,60	-0,30

originated the separation of species in two groups. On the left side of the biplot we can find those species that were identified exclusively in the oak site and whose distribution is strongly conditioned by a thick humus layer and/or a higher water content in soil or humus horizons. These are represented by the species *Bilobella aurantiaca* (Bau), *C. debilis* (Cde), *T. hygropetrica* (Thy), *Protaphorura* gr. *armata* (Pgar), *P. armata* (Par) and *Xenylla grisea* (Xgr). Plotted in the same area of the graph are those species that, despite their highest abundance in the autochthonous stand, also appear in the eucalyptus site. However, species like *H. major* (Hma), *Pseudosinella* sp. (Psp), *I. minor* (Imi), *X. armatus* (Xar), *Onychiurus* sp. (Osp), *Mesaphorura* sp. (Msp), *C. scpelliferus* (Csc) or *Lepidocyrtus* sp. (Lsp) have their distribution there confined to those sampling points having a high carbon and organic matter contents in the humus or soil layers.

On the positive side of the graph we can find those species characterising the eucalyptus stand and whose distribution is not so conditioned by the soil factors mentioned above and being capable of colonising more open habitats. Their distribution is strongly correlated with soil temperature, wich may indicate the presence of more exposed microhabitats. This group is represented by those species having a dominant position in this stand like *D. portucalensis* (Dpo), *C. engadinensis* (Cen), *C. tergilobata* (Cte), *P. bougisi* (Pbo), *P. gisini* (Pgi), *Entomobrya* sp. (Esp), *Entomobrya* juv. (Ejuv) and *T. proxima* (Tpr).

On axis two, which represents only 14.4% of total variability, the factor that influences most the distribution of the species in the biplot is soil pH (Fig. 4 – Table IV). Species like *Xenylla schillei* (Xsc), *Pseudosinella picta* (Ppi) and *Superodontella gisini* (Sgi), despite poorly represented in the community, are present only in *Alfa* experimental unit from the oak site, characterised by having a low soil pH. *Entomobrya multifasciata* (Emu) has a more widespread distribution, but its highest abundance was found also on those sampling points having also a low soil pH.

DISCUSSION

Despite the absence of significant differences between both sites in relation to abundance and number of taxa, the replacement of oak by eucalyptus led to a change in biodiversity patterns and in the structure of Collembola community.

At the oak site, the community is dominated by the generalist forest species *F. quadrioculata*, which was replaced at the eucalyptus stand by another generalist species, *T. proxima*. The dominance of isotomids has been reported by Lauga-Reyrel & Deconchat (1999) in fragmented mixed oak coppices, and may be explained by their high reproduction rate. The high abundance of these two species strongly influenced the values of biodiversity indicators obtained; the low species diversity and species richness values calculated for the eucalyptus site were mostly influenced by the associated low evenness values than by the lower number of taxa. The removal of these two species from the calculations led to a more balanced situation, where the difference between values from each site was negligible, considering both data at experimental unit level or globally (data not presented). Arbea & Jordana (1985), when analysing the effects on collembola communities by replacing black oak for Japanese larch, also found a lower number of species and a lower species richness in the exotic site when compared to the autochthonous stand, but not a lower species diversity nor evenness. This means that the values obtained in this study, although real, should be evaluated carefully.

Regarding community composition, however, the differences between sites are not apparent. Shifting from oak to eucalyptus led to changes in vegetation structure and microhabitat configuration, as indicated by the differences in soil parameters. This caused a change in species composition, with the disappearance/reduction of those species that could not cope with the new eco-climatic conditions, and the increase of other species capable of doing so. In general we observe a reduction in the abundance and number of taxa of Isotomidae[1] and Onychiuridae groups, and an increase in the representation of the Neanuridae and especially the Entomobryidae.

Despite all groups being characterised here mostly by generalist forest species, the first two are represented by species having more demanding requirements in terms of microhabitat configuration, especially in terms of moisture conditions and/or organic matter content. These are species mentioned earlier that are confined to those places where these conditions are met; some were only identified at the oak site, others are also present at the eucalyptus site, but only in certain sampling points. The exceptions on these groups are *T. proxima* (Tpr) and *P. gisini* (Pgi) that were able to increase their abundance at the eucalyptus site. A similar decrease in Isotomidae was also observed in other studies dealing with the reforestation of this exotic species (Gama *et al.*, 1991; Sousa & Gama, 1994; Sousa *et al.*, 1997).

At the eucalyptus site a better representation of the Entomobryidae, Neanuridae and also of some Hypogastruridae was expected. Species belonging to the first group are known to have a high reproductive and dispersal rates and the ability to colonise open spaces (Ardanaz & Jordana, 1986; Luciañez *et al.*, 1988). This is the case of several *Entomobrya* and *Lepidocyrtus* species (Esp, Ejuv, Lsp), but also of *H. major* (Hma) and *P. infrequens* (Pin). Some of these, however, have their distribution conditioned by certain soil parameters, appearing mainly on those sampling points with a better quality of the humus horizon. The species from the other two groups increasing in number at the eucalyptus stand, namely *C. engadinensis* (Cen), *C. tergilobata* (Cte), *C. gibbosa* (Cgi), *D. portucalensis* (Dpo) and *P. bougisi* (Pbo), are known to be present in dry places or not to be affected by the reforestation processes with this exotic species, having a broad distribution also in other eucalyptus sites in central and southern Portugal (Barrocas *et al.*, 1998; Gama *et al.*, 1994a, 1995).

The results obtained here confirm that species composition is strongly influenced by abiotic parameters of the organic horizons of the soil; besides moisture, the quantity and quality of the organic matter clearly affects the distribution of collembola species. This is in agreement with Hasegawa (2001) that states that the amount and composition of organic matter in a mixed forest were the main factors ruling the organization of microarthropod (collembola and mites) communities.

In this case, the plantation of a small area with eucalyptus and the almost absent management practices, implying the non existence of periodical disturbances in the system, led to the existence of a spatial heterogeneity of eco-climatic conditions, as supported by the difference in

[1] Analysing data on Table I without *F. quadrioculata* and *T. proxima* the abundance and number of taxa of the Isotomidae decreases significantly in eucalyptus.

vegetation structure and by the variability in the soil parameters among experimental units. These allowed the dispersion not only of species with a more ubiquitous distribution, but also the settlement of some taxa more demanding in terms of habitat configuration. Despite, this shift torwards eucalyptus led to a change in community composition but not to a strong loss of biodiversity (at least as we measure it) when compared to other case studies where larger areas were planted and regular management practices were adopted. The close link between management practices and habitat configuration is the key issue. The greater the change induced in the habitat by the installation of the plantation, especially on those soil factors ruling species distribution (soil moisture and organic matter content and quality), the higher the magnitude of effects.

This addresses the question raised in the introduction, but of course the same question can and should be posed in case of other tree species, exotic or not. In any case, the change in community structure even in the less disturbed situations, in this case with a general reduction of rare or restrictive distribution species and the increase of expansive taxa, is a fact and should not be disregarded. What are the implications of this change for the regional biodiversity pool and for the stability and functioning of the system is beyond the scope of this paper. However this type of studies evaluating diversity patterns on relatively small forest areas, can contribute for further research on biodiversity at landscape level and addressing issues like changes in land-use.

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REFERENCES

Arbea, J.I. & R. Jordana (1985). Efecto de una repoblación con coníferas en un robledal de Navarra sobre los colembolos edáficos. *Boletim da Sociedade Portuguesa de Entomologia*, 2: 277-286.

Ardanaz, A. & R. Jordana (1986). Estudio ecológico sobre la fauna colembológica de las Peñas de Echauri, Navarra. (Insecta, Collembola). III. - Prado-Matorral. *Actas de las VIII Jornadas de A y E.*, 253-260.

Barrocas, H.M., M.M. da Gama, J.P. Sousa & C.S. Ferreira (1998). Impact of reafforestation with *Eucalyptus globulus* Labill. on the edaphic collembolan fauna from Serra de Monchique (Algarve). *Miscel.lània Zoològica*, 21: 9-23.

DGF (2001). *Inventário Florestal Nacional, Portugal Continental – 3ª revisão, 1995-1998.* Direcção Geral de Florestas. Ministério da Agricultura do Desenvolvimento Rural e das Pescas, Lisboa, 234 pp.

Ferreira, C.S., M.M. da Gama, J.P. Sousa & T.M. Vasconcelos (1994). Comparative study of the collembola populations from a *Pinus pinaster* Aiton forest and a *Eucalyptus globulus* Labill. plantation. *Ciência Biológica Ecology & Systematics*, 14: 19-34.

Figueiredo, M.C., M.T. Cabral, S.C. Martins & M.M. da Gama (1985). Nota prévia sobre um estudo comparativo das populações de Colêmbolos de eucaliptais (*Eucalyptus globulus* Labill.) de várias idades e de pinhal (*Pinus pinaster* Ait.). *Boletim da Sociedade Portuguesa de Entomologia*, 2: 221-234.

Gama, M.M. da, A.F.A.M. dos Santos & A. Nogueira (1989). Comparaison de la composition de populations de Collemboles de peuplements d' Eucalyptus (*Eucalyptus globulus*) et de Chêne-liège (*Quercus suber*). *Proceedings of the 3rd International Seminar on Apterygota*, 339-345.

Gama, M.M. da, A. Nogueira & A.F.A.M. dos Santos (1991). Effets du reboisement par *Eucalyptus globulus* sur les Collemboles édaphiques. *Revue d'Écologie et de Biologie du Sol*, 28: 9-18.

Gama, M.M. da, J.P. Sousa & T.M. Vasconcelos (1994). Comparison of Collembolan Populations from Portuguese Forests of *Quercus rotundifolia* Lam. and *Eucalyptus globulus* Labill, pp. 201-214. *In "Professor Germano da Fonseca Sacarrão (1914-1992)".* Arquivos do Museu Bocage Ed., Lisboa, 383 pp.

Gama, M.M. da, T.M. Vasconcelos & J.P. Sousa (1994a). Collembola diversity in Portuguese autochthonous and allochthonous forests. *Acta Zoologica Fennica*, 195: 44-46.

Gama, M.M. da, J.P. Sousa & T.M. Vasconcelos (1995). Comparison of Collembolan populations structure from Portuguese forests of *Pinus pinaster* Aiton and *Eucalyptus globulus* Labill. *Bulletin Entomologique de Pologne*, 64: 77-89.

Hsegawa, M. (2001). The relationship between the organic matter composition of a forest floor and the structure of a soil arthropod community. *European Journal of Soil Biology*, 37: 281-284.

Lauga-Reyrel, F. & M. Deconchat (1999). Diversity within the Collembola community in fragmented coppice forests in south-western France. *European Journal of Soil Biology*, 35: 177-187.

Luciañez, M.J., M.M. Pascual & J.C. Simón-Benito (1988). Estudio colembologico de los robledales del Macizo Central de la Sierra de Gredos (Sistema Central). *Actas II Jornadas sobre la Sierra de Gredos.*

Magurran, A.E. (1991). *Ecological diversity and its measurement.* Chapman and Hall, London, 179pp.

Pinto, C., J.P. Sousa, M.A.S. Graça & M.M. da Gama (1997). Forest Soil Collembola. Do tree introductions make a difference? *Pedobiologia*, 41: 131-138.

Sousa, J.P. & M.M. da Gama (1994). Rupture in a Collembola community structure from a *Quercus rotundifolia* Lam. forest due to the reafforestation with *Eucalyptus globulus* Labill. *European Journal of Soil Biology*, 30: 71-78.

Sousa, J.P., J.V. Vingada, H. Barrocas & M.M. da Gama (1997). Effects of introduced exotic tree species on Collembola communities: the importance of management techniques. *Pedobiologia*, 41: 145-153.

Ter Braak, C.J.F. (1986). Canonical Correspondance analysis: a new eigenvector technique for multivariate direct gradient analysis. *Ecology*, 67: 1167-1179.

Vasconcelos, T.M., M.M. da Gama & J.P. Sousa (1994). Estudo Comparativo da Biodiversidade Colembológica em Povoamentos de Pinheiro bravo e de Eucalipto. *Silva Lusitana*, 2: 179-191.

Zar, J.H. (1996). *Biostatistical Analysis.* Prentice-Hall, London, 718pp.